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EVALUATION OF HEAT- AND BLAST-PROTECTION MATERIALS

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16. Abstract

A program was initiated at the Kennedy Space Center in December 1967 and conducted through December 1969 by the Materials Testing Branch, for the Design Directorate, Mechanical Design Division, to evaluate the performance of heat- and blast-protection materials for ground support equipment used during the Apollo/Saturn launches.

Vendors supplying materials believed to be generally suitable for heat and blast protection were contacted; some subsequently submitted sufficient material for launch-exposure tests. Tests were made during the Apollo/Saturn 502, 503, and 505 launches. Tests were also made in a local laboratory, as an alternative to the restrictive requirements of launch-exposure tests, to determine the effects of torch-flame exposure on ablative materials.

Five materials were found to be satisfactory in all major test categories. It was determined that torch-flame tests can probably be utilized as an acceptable substitute for the booster-engine-exhaust exposure test for basic screening of candidate materials.

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EVALUATION OF HEAT- AND BLAST-PROTECTION MATERIALS

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INTRODUCTION

This is the summary report of a program, conducted by the Materials Testing Branch (MTB) for the Design Directorate, Mechanical Design Division, at Kennedy Space Center (KSC) to evaluate the performance of heat- and blast-protection materials for ground support equipment. The program, which was initiated in December 1967 by a request from Mr. A. Zeiler, remained active through December 1969, at which time the experimental work was terminated.

The impetus for an evaluation program on heat- and blast-protection materials was provided by:

The requirement for a means of protecting various items of ground support equipment from heat and blast effects during launch vehicle firings.

The lack of suitable test data to indicate what types of materials could provide adequate protection against the heat fluxes generated by the Saturn V booster engines.

The need for providing adequate heat and blast protection at the lowest overall cost to NASA.

At the inception of the evaluation program, a single material, Dynatherm D-65, was primarily planned for application to the launch structures at Launch Complex 39, and some experience was gained with this material during the A/S 501 launch. It was considered that a basic test requirement for any additional candidate materials should be exposure to the booster engine exhaust during an actual launch. Therefore, it was with some urgency that plans were made to obtain materials for testing during the A/S 502 launch.

Contacts were made with vendors supplying materials believed to be generally suitable for heat and blast protection. Those vendors indicating an interest in the program were requested to provide sufficient material initially for launch-exposure tests, with the understanding that those materials performing well in the first launch exposure would be subjected to additional testing as needed to determine their overall qualifications for use at KSC.

MATERIALS

Candidate coatings for the program included ablative materials, passive insulators, intumescent paints, and heat-resistant paints. A vendor source list was supplied to the MTB by the Mechanical Design Division. As a result of initial contacts made by the MTB, 11 vendors indicated an interest in supplying materials for evaluation. Twenty-seven materials supplied by these 11 vendors were used in the first booster-engine-exhaust exposure test (the A/S 502 launch). Subsequently, other materials were supplied for evaluation by some of these same vendors and by one vendor whose materials were not evaluated in the initial test. A listing of the 27 original test materials and their sources is given in Table 1 (Appendix). The additional materials and their sources are listed in Table 2 (Appendix).

Test samples for the initial launch-exposure test were applied, in a thickness of 0.318 cm, to carbon steel panels 15.2 cm by 15.2 cm by 0.318 cm. The steel panels had been first coated with an inorganic-base, zinc-rich paint, which is used widely as an anti-corrosion coating on exposed structures at KSC. Some of the panels were sent to vendors for application of the heat-resistant coatings. Other panels were retained by the MTB for application of coating materials supplied by the vendors. Test samples for the later launch-exposure tests were basically identical with those used in the initial test. Any departures from the original test configuration are noted in the data tables for the particular tests described in subsequent sections of the report. Samples for other types of tests were prepared by the MTB, from materials supplied by the vendors, in the forms needed for the various tests.

TEST PROCEDURES AND RESULTS

The overall test requirements for the evaluation program were established by the Mechanical Design Division, and these requirements are, in general, now incorporated in a KSC specification for heat- and blast-protection materials (Reference 1). In addition to the launch-exposure tests, data were needed on refurbishment characteristics, mixing and application, adhesion to painted steel base, flexibility, flammability, resistance to attack by hypergolic propellants (in event of spillage), possible reactivity with LOX (also in event of spillage), and the resistance to torch-flame exposure. As stated previously, the most urgent requirement in screening the various candidate materials was satisfactory performance in the launch-exposure test. Therefore, the chronology of the program was primarily established by the Apollo launch schedule. The mixing and application characteristics of the materials were evaluated during preparation of samples for the launch-exposure tests. The other tests were conducted as time and materials were available between, and subsequent to, launch-exposure tests.

Booster-Engine-Exhaust Exposure

This section of the report describes the launch-exposure tests conducted during the A/S 502, 503, and 505 launches. The procedures used in preparation and evaluation of the samples for these tests included mixing and application of the heat-resistant coating materials, and refurbishment of the test panels following launch exposure, both of which have become part of the overall test requirements. The results of the mixing and application and refurbishment evaluations of the materials originally tested in the A/S 502 launch are given in Tables 3 and 5 (Appendix). Performance of the "newer" materials was generally satisfactory in both respects. The overall results are also summarized in a subsequent section of the report.

A/S 502 Launch Exposure

Coating samples were applied to the steel test panels by the MTB and by some of the participating vendors. For the coating application done by the MTB, the vendor's recommendations were followed. For one of the coatings, a particular primer supplied by the coating manufacturer was applied over the inorganic-base, zinc-rich paint. With other coatings, no primer was required, and the material was applied directly to the zinc-rich paint surface. In instances where a primer was recommended but not required, the primer was applied. A single primer material was used for all such applications by the MTB--GE-SS4155 "Blue Primer." Table 3 (Appendix) shows the coatings and primers used, the panel designation for each sample, and other details of the coating application. In the instances of coatings applied by the vendor, details of coating application are shown when this information was supplied by the vendor. In the coating application sequence, the weight of each panel was determined immediately before the coating was applied. After the coating was applied and had cured, each panel weight was again determined.

As a part of the performance evaluation for the coatings, it was desired to know the temperature that each panel attained during the exposure to the booster engine exhaust. The time factor did not permit instrumentation of the panels with heat-sensing devices from which temperature recordings could be made. However, a series of temperature-indicating paints (Tempilaq) was applied to the back of each panel. These paints, which were applied as stripes, undergo a visible permanent change when a given temperature level is reached. The series applied to the panels covered a temperature range from 204°C to 1,371°C. The paints were also applied to several uncoated panels, which were attached face-up on the large plates in several different locations among the coated panels. It was expected that some indication of the direct exposure temperatures could be obtained from these samples, as well as the back-face temperatures from the coated samples.

The test panels with the heat-resistant coatings (or temperature-indicating paints) applied were attached to the large steel plates with 0.635-cm stainless steel machine screws. The spaces between the edges of each test panel and the base plate were sealed with a caulking material (Dow-Corning 92-041) to protect the temperature-sensitive paints on the back surface of the panels from the intrusion of moisture. The plates with the attached test panels were transported to the launch site (LC-39A) and were attached to the mobile launcher No. 2 deck at a point 55.9 cm from the deck opening. One plate (No. 1) was on the south side of the deck opening, and the other plate (No. 2) was on the east side of the opening. Figure 1 shows the initial appearance of the coated panels on Plate No. 1; Figure 2 shows the location of the plate in relation to the flame hole and one of the booster engines.

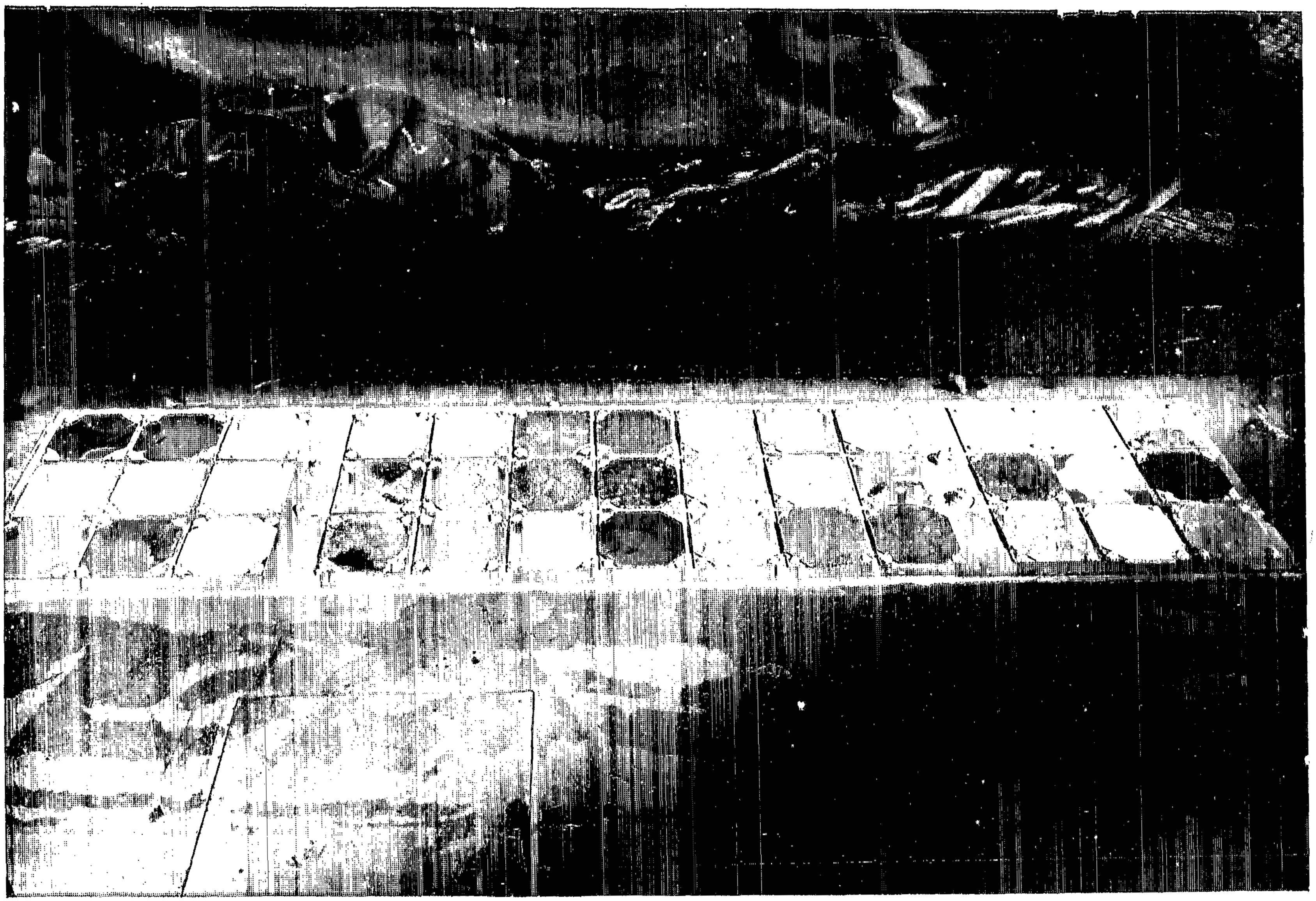

Figure 1. Test Fixture (Plate No. 1) with Panels, on Mobile Launcher Deck, for A/S 502 Launch

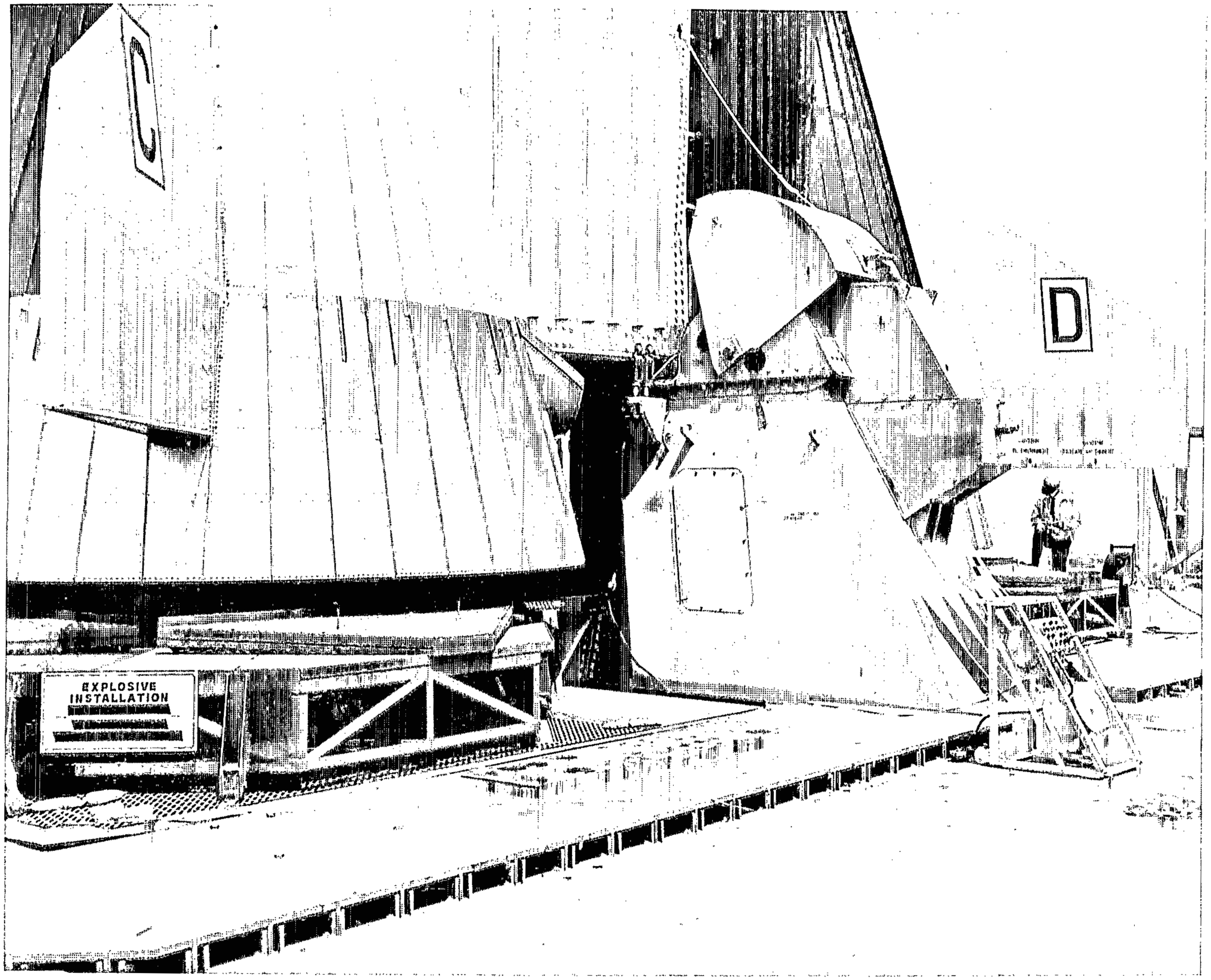

Figure 2. Position of Test Fixture Relative to Flame Hole and Booster Engine

In the period between the placing of the test samples on the mobile launcher deck and their heat and blast exposure during the A/S 502 launch, the samples were inspected for any effects of atmospheric exposure on the coatings. No significant changes from atmospheric exposure were noted. Immediately following the A/S 502 mission, the two plates with the attached panels were removed from the mobile launcher deck and transported to the Materials Testing Laboratory for examination.

Photographs were taken of the test panels for documentation of changes in their appearance as a result of exposure to the booster engine exhaust. The individual panels were then removed from Plates 1 and 2 and were inspected and evaluated by a panel composed of personnel from the Mechanical Design Division and the Materials Testing Laboratory. The temperature indications from the Tempilaq paint (applied to the panel backs), and the weight and thickness changes of the coatings were determined and recorded. Figure 3 shows an overall view of Plate 1 and the attached test panels. The general appearance of the panels after launch exposure can be seen in this photograph. The Tempilaq paints applied to the exposed face of several panels were removed, probably during water deluge.

The results of the evaluation of each coating, with respect to back-face temperature, material loss, and general appearance, are given in Table 4 (Appendix). The arbitrary rating for each coating material is also shown. These ratings were arrived at by the parameters previously listed. If one test panel for a given material showed a back-face temperature of less than 204°C, nominal material loss, and fairly even ablation, the material was given a "Good" rating, even though other test panels in the group did not perform as well. In some instances, panels prepared by the vendors appeared to have performed substantially better than the panels of the same material prepared by the MTB (e.g. Korotherm 792-700 and 792-701; Dynatherm D-65). With other materials, the converse was true (e.g. 190-J-4). The "Fair" rating was usually given to materials with nominal loss but with very uneven ablation, particularly when completely bare spots were present. The "Poor" rating generally reflects high back-face temperature, or very heavy material loss, or both.

Those materials receiving the "Good" rating were next evaluated for refurbishment characteristics. The thickness and weight of each of these materials with its char layer (if present) was determined. One-half of the coating surface was then wire-brushed to remove any char layer and other loose material. The panels were then reweighed to determine the weight of char removed, and the coating thickness was again measured. Fresh material was applied to the brushed half of each panel to restore coating thickness to 0.318 cm. The refurbishment characteristics for each material are shown in Table 5 (Appendix).

A/S 503 Launch Exposure

Test samples for the exposure to booster engine exhaust during the A/S 503 launch consisted of panels refurbished after the A/S 502 exposure test, newly prepared panels of several of the previously tested materials, several panels initially coated with

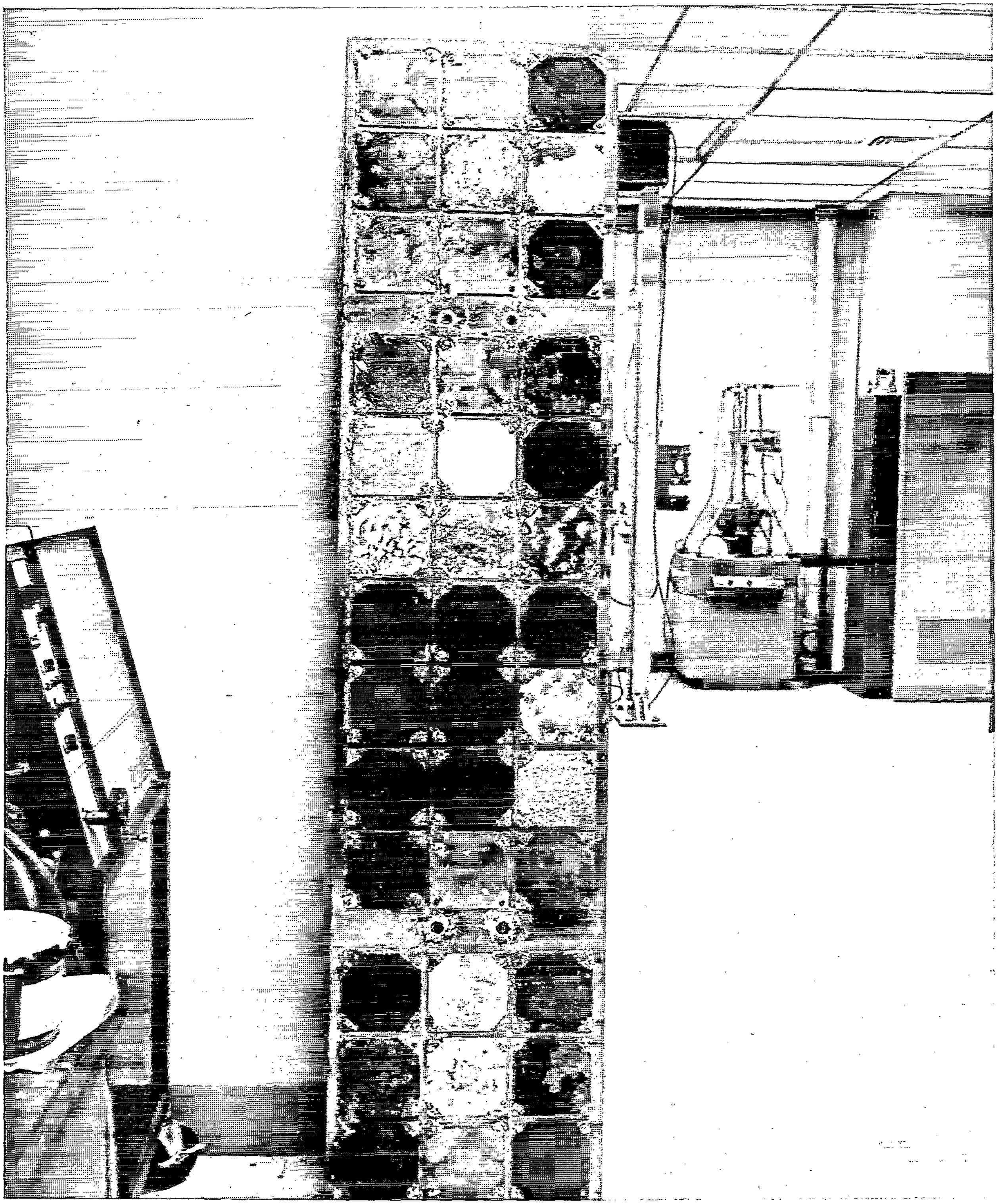

Figure 3. Plate No. 1 with Test Panels Following Exposure to A/S 502 Launch

Dynatherm D-65 and then overcoated with other ablative materials, and a previously untested material, E-320, supplied by Dynatherm for evaluation. General methods of preparation of "new" test panels were similar to those used in preparation of samples for the A/S 502 test. The total number of test panels (30) could be accommodated on one of the large steel test fixtures. In the assembly of the test fixture for the A/S 503 test, temperature-sensing strips (Tempilabels) were placed in contact with the back face of each steel test panel. These elements, which give indication by color change within 14°C increments of temperatures reached in the range of 121°C to 260°C, were expected to cover the back-face temperature range more effectively than that obtained with the Tempilaq in the A/S 502 test. Photographs were taken of the completed test fixture, and it was moved to the launch site and attached to the deck of the mobile launcher.

Following the A/S 503 launch, the test fixture was returned to the Materials Testing Laboratory for evaluation of the coatings. Photographs of the exposed samples were taken for documentation. Each of the samples was then removed from the base plate, and the weight and thickness of the remaining coatings were determined. The temperature sensors (Tempilabels) attached to the backs of the test panels were read to determine the maximum back-face temperatures experienced during exposure. The samples were then wire-brushed to remove any char that was found, and the weight and thickness of each coating were again determined.

The results of the sample analyses are given in Table 6 (Appendix). Comparison of the results of this test with those obtained in the original A/S 502 exposure suggests that the severity of the exposure was generally of greater degree in the A/S 503 launch, as indicated by weight and thickness losses. Five of the materials were considered outstanding on the basis of rate of ablation and uniformity of ablation. These were: DC 93-072, GE TBS 758, Dynatherm E-310F, Dynatherm D-320, and Raycom RPR 2138.

A/S 505 Launch Exposure

Materials selected for booster-engine-exhaust exposure during the A/S 505 launch included retesting of several materials that had performed well in prior tests (for the purpose of completing a list of acceptable materials) and several "new" materials, including three elastomeric materials furnished in sheet form, and several materials supplied by Universal Propulsion Company. The sheet materials were cemented to the steel test panels, and the other materials were trowelled on the panels (as usual). Temperature-sensing elements (Tempilabels), covering the temperature range from 66°C to 260°C in 14°C increments, were placed on the backs of the test panels, and the panels were attached to the large steel test plate. In addition to the ablative-material test panels, the plate had inorganic-zinc-paint-coated steel panels attached to it, also with the Tempilabels applied to the back of each panel. These zinc-painted steel panels, in thicknesses of 0.318 cm, 0.635 cm, 1.27 cm, 1.91 cm, and 2.54 cm, were evaluated to determine the back-face temperatures attained, as a function of thickness, without the protection of ablative coatings. The plate with the attached panels was photographed and was then transported to the mobile launcher for attachment to the launcher deck near the flame hole.

The results of the A/S 505 launch-exposure test are given in Table 7 (Appendix). Several of the previously tested materials performed very satisfactorily in this test, notably Dynatherm E-310F and E-320, and Dow-Corning 20-103 and 93-072. The Korotherm 792-703/792-704 was marginally acceptable on the basis of weight loss, and the Dow-Corning 93-058 (a "new" material) and the Dynatherm D-65 panels showed excessively high weight loss. Several new materials were exceptionally resistant to the heat and blast effects, in particular the Goodrich EP-87 and the Upcote 16030, 10035, 14038, 16031, 14041, and 07006. Test data on the "unprotected" zinc-painted steel panels of various thicknesses indicated that, in plate thicknesses of 1.27 cm or greater, the back-face temperatures attained during launch are surprisingly low -- approximately 107°C -- in areas of the launcher deck fairly close to the flame hole.

Adhesion

Test of adhesion characteristics of 15 ablative materials that were rated "Good" in the A/S 502 launch test were performed initially, and subsequently similar tests were performed with new materials whose performance in the later launch-exposure tests warranted further consideration. The test samples were 0.318-cm-thick strips of the ablative material 2.54 cm wide and 20.32 cm long, applied to steel strips (of similar size) that had been primed with inorganic-base, zinc-rich paint. In addition, some limited tests were performed to evaluate the adhesion of several materials to bare steel and to other ablative materials. This latter type of test was primarily to evaluate the adhesion characteristics of dissimilar materials, such as might be applied during refurbishment of launch structures.

In the preparation of the adhesion test specimens, a 2.54-cm length at one end of the specimen strip was deliberately separated from the base metal with masking tape to allow access for gripping. The separated ends of the specimen were gripped in the jaws of an Instron testing machine, and the specimen was aligned normal to the loading axis of the testing machine. The specimen was then pulled in the machine at a crosshead-travel rate of 0.402 cm per second. A load-deflection curve was recorded, and the average adhesion load for each test was determined for a band length of 12.7 cm, the first and last 2.54 cm of separation being neglected.

The results of the adhesion tests for the 15 original materials applied to zinc-painted steel are given in Table 8 (Appendix). Table 9 (Appendix) gives the results of adhesion tests of several materials applied to bare carbon steel, and Table 10 (Appendix) gives the results of adhesion tests of four ablative materials applied to steel previously coated with Dynatherm D-65 (simulating refurbishment bonds). Additionally, adhesion tests similar to those reported in Table 8 (Appendix) were performed with Dynatherm E-320, Upcote 10-035, and Dow-Corning 93-058 (applied to zinc-coated steel). The E-320 and the 10-035 had excellent adhesion characteristics. The bond strength of the E-320 exceeded the tensile strength of the material, and the adhesion of the Upcote 10-035 was 11.9 kg/cm. The adhesion of the 93-058 was very poor, well below 1.13 kg/cm. Generally, materials having an adhesion of 5.65 kg/cm are considered acceptable. If a definitive load value cannot be obtained, because of tensile failure of the test strip, indication of good adhesion is implied by removal of the zinc paint applied to the steel base. Of the materials tested, five were considered to have unacceptably low adhesion. These were: GE RTV 511, GE TBS 542, Fuller 190-J4, Raycom RPR 435, and Dow-Corning 93-058.

Flexibility

The heat- and blast-resistant coatings are applied to structural parts of various shapes and to relatively large flat areas, such as the side panels of the tail service masts. If the cured coating is excessively hard and stiff, it can be separated from the base metal because of the stagnation pressures sustained during launch. Separation would begin along an edge where adhesion is inadequate. Inflexible coatings could separate as complete sheets, leaving large unprotected areas exposed to later stages of the booster engine exhaust. Examination of test panels exposed in the launch tests previously described indicates that this may have occurred in several instances. To prevent this occurrence, the cured coatings must be reasonably flexible and soft.

The test requirement for flexibility is that a 0.318-cm-thick sheet of the cured coating be bent around a 7.6-cm-diameter mandrel without cracking of the coating materials. Two materials failed this test: Martyte Presstite 1192 and Raycom RPR 2138.

Flammability

Flammability tests were performed on the 15 materials evaluated in the A/S 502 launch exposure and on additional materials whose properties warranted further consideration. The tests were performed generally in accordance with ASTM D 1692-62T. This method utilizes sheet samples of the test materials, 5.08 cm by 15.2 cm by 0.635 cm, supported on a metal screen. In the first tests performed with these ablative materials, some modifications were made in the ASTM test procedure to provide more realistic conditions with regard to application of the test materials. Two test series were conducted on the original flammability tests. In the first, the samples were supported horizontally, from one end only, as cantilevers. The specimen was ignited by applying a Bunsen-burner flame to a 2.54-cm length of the outer end for 60 seconds. After 60 seconds, the Bunsen burner was removed, and the propagation time of flame down the length of the sample, or the time to flame extinction, was obtained. In the second series, the specimen was supported horizontally on an aluminum plate with a 2.54-cm length of the specimen overhanging the aluminum support plate. The Bunsen-burner flame was applied to the 2.54-cm free end, held for 60 seconds, and removed. The time for flame extinction was determined. The results of these tests are given in Table 11 (Appendix).

Additional tests were performed on four materials with specimens of two different sheet thicknesses -- 0.635 cm and 0.318 cm -- but with the samples supported on

0.635-cm-grid hardware cloth as specified in ASTM D 1692-62T. The Bunsen burner, with a wing tip, was applied to the sample end for 60 seconds, the flame removed, and the time to flame extinction was determined. The results of these tests are given in Table 12 (Appendix). These data indicate that sheet thickness has no important effect on flame-extinction time of the ablative materials within the thickness range usually applied to the launch structures.

Three of the materials evaluated in the first test group, Korotherm 792-700/790-704, Raycom RPR 435, and Korotherm 792-701/792-702, were considered unsatisfactory on the basis of flammability characteristics because of their tendency to sustain burning and to burn beyond the edge of the heat sink. The flammability properties of the Raycom RPR 2138 were questionable, because of its long-burning characteristics. It was decided to submit this material to further flammability tests, along with several other materials for comparative purposes. It was believed that tests in accordance with ASTM D-635, which utilizes smaller test specimens, might be more sensitive in delineating excessive flammability tendencies. In these tests, specimens 12.7 cm long, 1.27 cm wide, and 0.318 cm thick were used. The specimen was held horizontally at one end in a gripping fixture, with the specimen axis at 45 degrees; a Bunsen-burner flame was applied to the free end for 30 seconds and then removed; and time of burning along the lower edge was recorded. The results of these tests on RPR 2138, DC 20-103, Dynatherm E-310F and D-65, and Korotherm 792-703/792-704 are given in Table 13 (Appendix). These data indicate that the Raycom RPR 2138 has much greater flammability tendencies than the other materials evaluated with the ASTM D-635 test procedure.

Exposure to Hypergolic Propellants

Because of the possibility of accidental spillage of hypergolic propellants during loading at the launch sites, heat- and blast-protection materials used on the launch structures should be relatively resistant to attack by the propellants or, at least, should not be violently reactive if brought in contact with them. Accordingly, hypergolic propellant exposure tests were conducted with the more promising candidate ablative materials, which were: Dynatherm D-65, E-310F, and E-320; Dow-Corning 20-103 and 93-072; Raycom RPR 2138; Korotherm 792-703/792-704; GE TBS 758; and Universal Propulsion Upcote 10-035.

The exposure tests utilized 2.54-cm squares of each material, 0.635 cm in thickness. Each sample was placed in a dish, and several drops of propellant were applied to simulate spillage. Two propellants were used -- Aerozine 50 (50:50 mixture of hydrazine and unsymmetrical dimethylhydrazine) and nitrogen tetroxide (N_2O_4). None of the materials were noticeably affected in 600 seconds of exposure to Aerozine 50. In the tests with nitrogen tetroxide, there were no violent reactions, although the reaction with the Upcote 10-035 was vigorous. In 600 seconds, no discoloration or other activity was observed with Korotherm 792-703/792-704, DC 20-103, DC 93-072, or E-310F. Slight surface discoloration was noted with TBS 758, E-320, and RPR 2138. Considerable leaching of some of the constituents of D-65 was noted along the edges of the sample, where the 904 topcoat was not present. There appeared to be little activity of the N_2O_4 where the 904 topcoat was intact. The Upcote 10-035 was the most reactive of the materials to N_2O_4. However, there was no evidence of ignition or otherwise violent effects. The reaction was essentially one of relatively rapid deterioration of the ablative material. Consequently, it was decided that none of the materials tested should be disqualified on the basis of possible hazard generated by exposure to hypergolic propellants.

Exposure to Liquid Oxygen

The possibility of a liquid oxygen spillage on the launch structures dictates the requirement that materials applied to these structures for heat and blast protection be unreactive on contact with LOX. Earlier in the evolution of both the materials and the test requirements for their qualification, consideration was given to the possible effects of LOX-impact sensitivity of materials applied to the launch structures. This consideration was based on the following rationale: a LOX spillage coincident with mechanical shock supplied by impact from a falling object could produce conditions resulting in detonation of LOX-impact-sensitive materials. Consequently, LOX-impact tests were performed by the Marshall Space Flight Center (MSFC) (References 2 and 3) on materials then available as thermal insulators. One material, Dynatherm D-65, was provisionally qualified as being LOX-compatible. Tests performed at MSFC in accordance with MSFC-SPEC-106B (Reference 4) showed that, in thicknesses of 0.16 cm or greater, the D-65 could be considered acceptable, with the stipulation that batch-testing of the material be performed.

As experience was gained through launch-exposure performance of the heat- and blast-protection materials (and the continuing test program with them), the need for LOX-impact compatibility was given further consideration. As stated in KSC DTI-M-15A (Reference 5), the requirements with regard to LOX (or GOX) exposure were modified, with the result that qualification of materials by the LOX-impact test is no longer required for applications involving exposure directly to the atmosphere. This modification is also reflected in the provisions of KSC-SPEC-F-0006A, for Heat and Blast Protection Coating Materials (Reference 1). In part, this modification was based on the results of a series of special LOX-impact tests, performed at the request of the Mechanical Design Division by the Materials Testing Branch, utilizing the KSC Oxygen-Compatibility Test Facility. The test specimens consisted of several of the ablative coating materials, some prepared in the Materials Testing Laboratory, one material (D-65) in tape form, and other materials obtained from the launch structures where they had been applied and exposed to the environment for some time. Some of the materials prepared in the laboratory were tested in "lab-clean" condition; others of the samples were deliberately contaminated with hydraulic fluid. It was believed that the testing of such a group of samples would give greater insight into the basic LOX-impact sensitivity of the various types of ablative materials and into the effects of surface contaminants on LOX-impact sensitivity of the materials.

The results of these LOX-impact tests are given in Table 14 (Appendix). The intensities of the reactions observed were rated according to an arbitrary scale as follows:

Rating	Description of Reaction
Faint	Barely visible light flash
Slight	Readily visible (but not intense) light flash
Appreciable	Very intense light flash
Considerable	Very intense light flash with burning of material for more than 2 seconds.

In some instances, the visible reactions were accompanied by audible reports. These instances are noted in the data table. Several of the materials in the thickness range of normal application (approximately 0.318 cm) and in the "lab-clean" conditions (or exposed to the atmosphere in the KSC Industrial Area for 16 days) were basically unreactive in this particular test series. Both the Dynatherm D-65 and the Dow-Corning 20-103 materials that had been obtained from the launch structures were LOX-impact-sensitive to some degree. Application of hydraulic fluid to the materials appeared to have increased the sensitivity in some instances (e.g. the Dynatherm tape) but had no apparent effect on sensitivity in other instances (e.g. Dynatherm E-320 and Korotherm 792-703/792 704). In one instance with Dow-Corning 20-103 (which was found to be generally LOX-impact-sensitive to a minor degree), the application of hydraulic fluid resulted in no reactions in a test series of 20 drops.

The results of the LOX-impact tests should be taken as indication that the ablative materials, whether they are inherently sensitive to LOX-impact conditions or not, may become sensitive by the adsorption of atmospheric contaminants or the spillage of contaminants such as hydraulic fluid.

None of the materials were basically reactive with LOX as the result of direct contact (simulated spillage) in the absence of impact.

Torch-Flame Exposure

As an adjunct to the major part of the program, tests were performed to determine the effects of torch-flame exposure on a number of the ablative materials. The purpose of these tests was to provide a possible means for evaluating the heat and blast performance of the coatings as an alternative to the launch-exposure test. If it could be established that the torch-flame exposure was essentially equivalent to launch exposure in rating the ablative materials, then it might be possible to qualify new candidate ablative materials without the rather restrictive time requirements inherent in the launch schedule.

The test procedures were based on an ASTM specification -- E-285-65T, Oxyacetylene Ablation Testing of Thermal Insulation Materials. Certain modifications were made to the procedures to provide conditions more suitable for the intended application. The ASTM specification provides for the use of a commercial welding torch nozzle (e.g. Victor Type 4, No. 7), with a single orifice 0.326 cm in diameter. With this nozzle, the area of flame impingement on the sample is relatively small, and the presence of small voids in the ablative coating has a significant effect on the test results. The torch tests for the reported program were performed with a multiple-orifice nozzle that provided a torch flame area of 5.08 cm by 5.08 cm. Therefore, the area of test specimen "sampled" in the test was large enough so small void areas would not have as profound an effect on the test results.

The torch tests were performed by Continental Test Laboratories, Fern Park, Florida, under contract to KSC, utilizing ablative material samples prepared by the Materials Testing Branch. The samples, which were 10.2 cm by 10.2 cm sheets, 0.635 cm thick, consisted of 16 materials representing a wide range of performance in the launch-exposure tests. The test procedure consisted basically of the following:

> The sample was mounted (in a vertical position) in a test support fixture, and a thermocouple, connected to a temperature recorder, was placed in contact with the back face of the sample.
>
> The torch, which was mounted in a retractable fixture, was fired using acetylene fuel only at first and was then supplied with oxygen automatically at the proper time interval to attain the desired flame characteristics. The torch was then positioned rapidly, by a hydraulic actuating system, so that the flame impinged on the center of the test specimen, and the test timer was initiated. The distance from the torch face to the specimen, at the initiation of the test, was nominally 2.54 cm. Calibration of the torch flame so positioned with respect to the specimen showed a heat flux of approximately 135 watts/sq cm. The torch-flame exposure was continued until specimen burn-through occurred or for 180 seconds. The torch-test facility is shown in Figures 4, 5, and 6.

From the test data obtained in the torch-flame tests, two parameters were calculated: insulation index, $\Delta 80°C$, $\Delta 180°C$, $\Delta 380°C$; and erosion rate. The insulation indexes are defined as follows:

$$I_T = \frac{tT}{d} ,$$

where: I_T = insulation index at temperature T (sec/cm)

tT = time for back-face temperature changes of 80°C, 180°C, 380°C from ambient (sec).

d = thickness of specimen (cm).

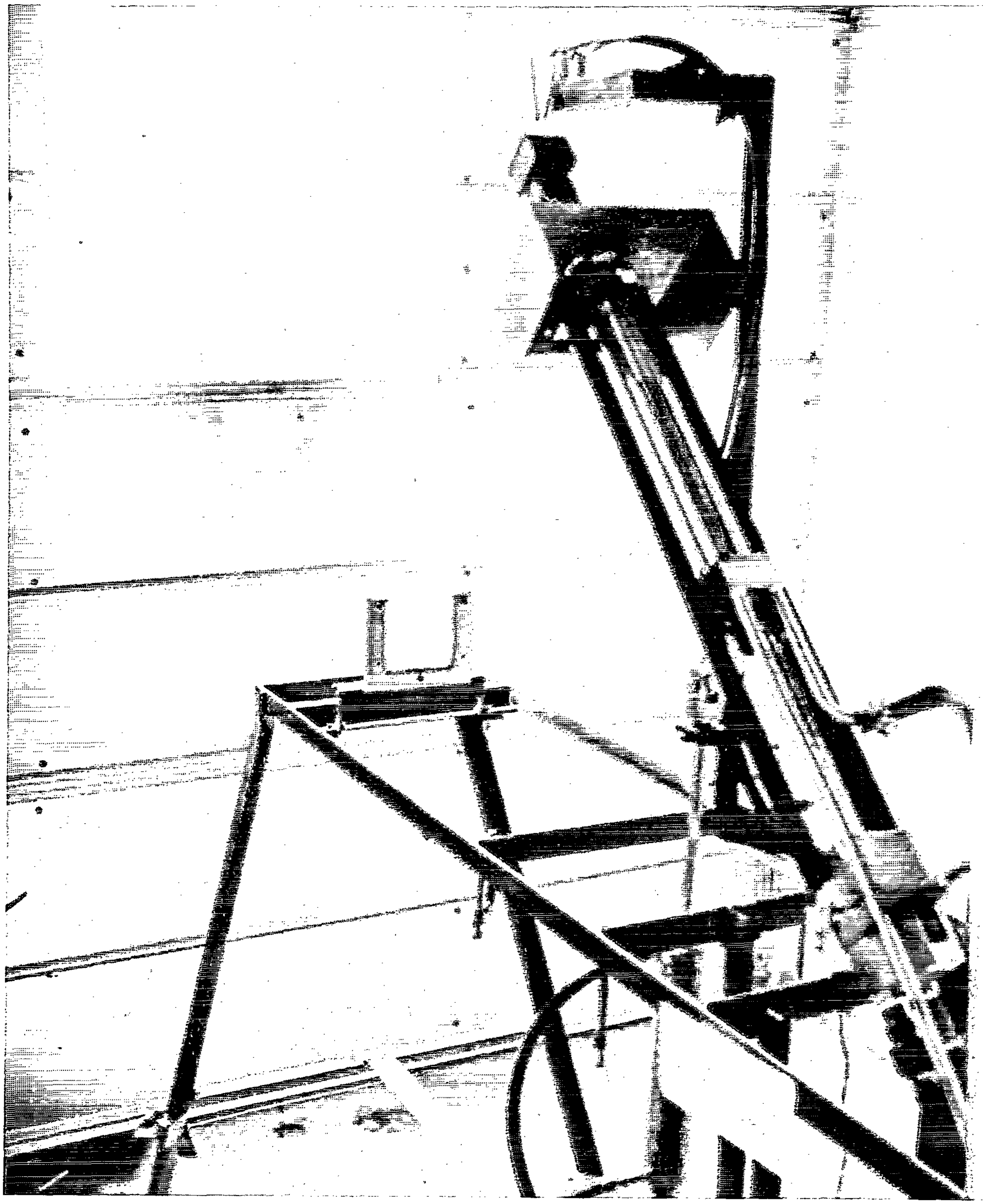

Figure 4. Test Stand and Torch, with Sample in Place for Testing

Figure 5. Torch Flame Impinging on Specimen During Test (Thermocouple is positioned on back face of specimen)

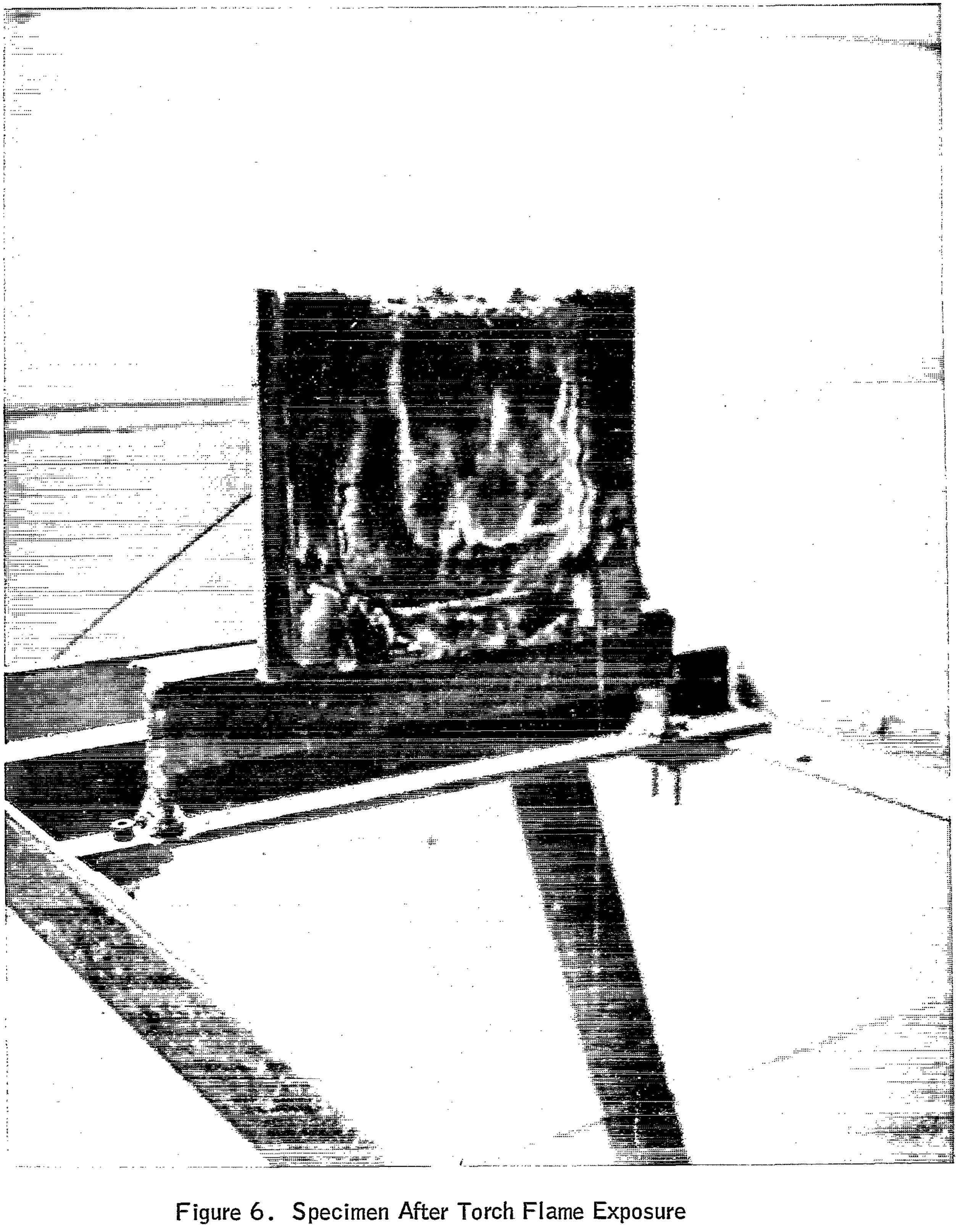

Figure 6. Specimen After Torch Flame Exposure

Erosion rate is defined as follows:

$$E = \frac{d}{b}$$

where: E = erosion rate (cm/sec)

d = thickness of specimen (cm)

b = burn-through time (sec)

In tests where burn-through did not occur before 180 seconds had elapsed (or occasionally because of torch flashback), the erosion rate was determined by measuring the depth of material that burned during flame exposure and dividing this distance by the time of exposure.

The results of the torch-flame tests on 16 ablative materials, presented as insulation indexes for ΔT's of 80°, 180°, and 380°C, and as erosion rates, appear in Table 15 (Appendix). For comparative purposes, the results of booster-engine-exhaust exposure tests are also presented. These latter results are average values of weight loss, including char removal. Some materials were tested in three launches, A/S 502, 503, and 505, whereas other materials were tested in only one launch. Therefore, it is not known whether a "fair" comparison between test methods can be drawn for all of the materials. Generally, the comparative data suggest that a procedure can be devised for screening materials by the torch test as a substitute for the rocket engine test. In a few instances, inconsistencies between results of the two types of tests were noted. Some of these, particularly in erosion rate, may be associated with basic differences in characteristics of the exposures. It is believed that the heat flux attained in the torch test is representative of heat fluxes experienced on the launch structures from booster-engine-exhaust impingement. However, the stagnation pressures from the torch test may be lower than those created by the booster engine. The inconsistencies may be also due in part to the method of preparing the samples for the torch test, which required "casting" the ablative material to a uniform thickness of 0.635 cm (with little dimensional tolerance allowed). As a result, more entrapment of air bubbles may have occurred than is usually experienced by trowelling of the 0.318-cm-thick coatings on the test panels for launch-exposure testing. A modified test sample for the torch test, similar to that used for the launch-exposure tests, would probably be satisfactory. Basically, it appears that levels can be established for the $\Delta T80°C$ insulation index and for the erosion rate that will ensure the sound selection, by the torch test, of materials for performance on the LC-39 launch structures. For example, values of 55 (minimum) sec/cm for $\Delta T80°C$ insulation index and 0.007 (maximum) cm/sec for erosion rate would appear to be reasonable tentative limits for this purpose.

CONCLUSIONS

An overall summary of the test results for each of the heat- and blast-protection materials is given in Table 16 (Appendix). Several materials from one vendor were not completely tested because, in the course of the program, the vendor selected a single material (e. g. Upcote 10-035) as being most generally suitable for complete evaluation. Several of the other materials were not completely tested because they were found to be unsatisfactory in one of the major test categories and were, therefore, basically unacceptable for use on the launch structures at KSC.

The following materials were found to be satisfactory in all major test categories and are so indicated in KSC-SPEC-F-0006-AMPL-4:

Dynatherm D-65 with 904 Topcoat
Dynatherm E-320
Dow-Corning 20-103
DeSoto Korotherm 792-703/792-704
Pfizer Firex 10-035 (originally Upcote 10-035)

Another material, Dynatherm E-310F, found to be basically acceptable, is essentially similar to E-320, but the E-310F components are somewhat less readily mixed for application. Therefore, the E-320 product is carried as the preferable material of the two.

Data obtained in torch-flame tests on a number of the ablative materials indicate that this type of test can probably be utilized as an acceptable substitute for the booster-engine-exhaust exposure test for basic screening of candidate materials.

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1. "Heat and Blast Protection Coating Materials, Specification for," KSC-SPEC-F-0006A, 2 June 1969, John F. Kennedy Space Center, NASA.

2. Key, C. F. and Riehl, W. A., "Compatibility of Materials with Liquid Oxygen," NASA TM X-985, August 1964.

3. Key, C. F., "Compatibility of Materials with Liquid Oxygen, III," TM X-53533, November 3, 1966.

4. "Testing Compatibility of Materials for Liquid Oxygen Systems," MSFC-SPEC-106B, October 6, 1967, Marshall Space Flight Center, NASA.

5. "Design Technical Instruction for Determining LOX Impact Sensitivity and Flammability Requirements for Materials Used where Contact with Liquid or Gaseous Oxygen is Expected or Possible," DTI-M-15A, March 28, 1969, John F. Kennedy Space Center, NASA.

APPENDIX

Table 1. Heat-Resistant Coatings Evaluated in the Initial A/S 502 Launch-Exposure Test

Vendor	Materials Designation	Type
Armstrong Cork	Insulcork K5NA	Ablative
DeSoto	Korotherm 792-700/792-704	Ablative
DeSoto	Korotherm 792-701/792-702	Insulative
DeSoto	Korotherm 792-703/792-704	Ablative
Dow-Corning	Silicone Rubber 20-103	Ablative
Dow-Corning	Silicone Rubber 93-072	Ablative
Dow-Corning	Silicone Rubber 92-041	Ablative
Dynatherm	D-65	Ablative
Dynatherm	E-310F	Ablative
Dynatherm	7275	Heat-Resistant Paint
Dynatherm	700	Ablative
Fuller Aircraft Finishes	190-J-7	Ablative
Fuller Aircraft Finishes	190-J-4	Ablative
General Electric	548-300	Ablative
General Electric	548-301	Ablative
General Electric	TBS-542	Ablative
General Electric	TBS-758	Ablative
General Electric	RTV-511	Ablative
Presstite	1192 Martyte	Ablative
Products Research and Chemical	PR-1955-BT-#12 Kit	Ablative
Raytheon	Raycom 435 RPR	Ablative
Raytheon	Raycom 2138 RPR	Ablative
Sperex	SP-21	Intumescent Paint
Thermal Systems	Thermo-Lag T-395-1	Ablative
Thermal Systems	Thermo-Lag T-395-3	Ablative
Thermal Systems	Thermo-Lag T-395-4	Ablative
Thermal Systems	Thermo-Lag T-800-6A	Ablative

Table 2. Heat-Resistant Coatings First Evaluated in the A/S 503 and A/S 505 Launch-Exposure Tests[1]

Vendor	Material Designation	Type
Dynatherm	E-320	Ablative
Dow-Corning	93-058	Ablative
Universal Propulsion[2]	Upcote[2] 16030	Ablative
Universal Propulsion[2]	Upcote[2] 14038	Ablative
Universal Propulsion[2]	Upcote[2] 07-006	Ablative
Universal Propulsion[2]	Upcote[2] 10035	Ablative
Universal Propulsion[2]	Upcote[2] 14050	Ablative
Universal Propulsion[2]	Upcote[2] 14041	Ablative
Universal Propulsion[2]	Upcote[2] 16031	Ablative
Goodrich	N322[3]	Ablative
Goodrich	N355[3]	Ablative
Goodrich	EP-87[3]	Ablative

1. These are coatings that were not available for evaluation in the A/S 502 launch-exposure test and were evaluated in the A/S 503 or 505 launches, or both. Some of the A/S 502 test materials were also evaluated in the two later launches.

2. Material now marketed by Pfizer Chemical under different trade name - "Firex."

3. Material supplied in sheet form, requiring cementing to steel substrate.

Table 3. Preparation of Coated Panels for A/S 502 Launch Exposure

Panel No.[1]	Coating Material	Primer[2]	Method of Coating Application	Coating Applied By	General Observations
1-168	Korotherm 792-700/792-704	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-164	Korotherm 792-700/792-704	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-111	Korotherm 792-700/792-704	GE-SS-4155	Spray	Vendor	
1-171	Korotherm 792-701/792-702	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-170	Korotherm 792-701/792-702	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-110	Korotherm 792-701/792-702	GE-SS-4155	Trowel	Vendor	
1-173	Korotherm 792-703/792-704	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-172	Korotherm 792-703/792-704	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-109	Korotherm 792-703/792-704	GE-SS-4155	Trowel	Vendor	
1-195	Dynatherm E-310F	None	Trowel	MTB	Application satisfactory.
2-193	Dynatherm E-310F	None	Trowel	MTB	Application satisfactory.
2-102	Dynatherm E-310F	None		Vendor	
1-156	Sperex SP-21	GE-SS-4155	Brush	MTB	13 coats applied. Application by brush satisfactory.

1. First digit in this number sequence refers to the designation of the large steel plate (1 or 2) to which the individual panels were attached. Last three digits refer to the particular panel designation.

2. When no primer was used, the surface of the zinc-rich undercoat was wire-brushed before the heat-resistant coating was applied.

Table 3. Preparation of Coated Panels for A/S 502 Launch Exposure (Continued)

Panel No.[1]	Coating Material	Primer[2]	Method of Coating Application	Coating Applied By	General Observations
1-153	Sperex SP-21	GE-SS-4155	Brush	MTB	13 coats applied. Application by brush satisfactory
1-147	GE-548-300	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-145	GE-548-300	GE-SS-4155	Trowel	MTB	Application satisfactory.
1-142	GE-548-301	GE-SS-4155	Cast	MTB	Not suitable for vertical surface application.
2-144	GE-548-301	GE-SS-4155	Cast	MTB	Not suitable for vertical surface application.
1-148	GE-TBS-542	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
1-150	GE-TBS-542	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
1-130	GE-TBS-758	GE-SS-4155	Trowel	MTB	Appeared to need elevated temperature (32.2°C) cure. Not considered entirely satisfactory.
2-132	GE-TBS-758	GE-SS-4155	Trowel	MTB	Appeared to need elevated temperature (32.2°C) cure. Not considered entirely satisfactory.
1-185	1192 Martyte	None	Roller	MTB	Application satisfactory.
2-184	1192 Martyte	None	Roller	MTB	Application satisfactory.

1. First digit in this number sequence refers to the designation of the large steel plate (1 or 2) to which the individual panels were attached. Last three digits refer to the particular panel designation.

2. When no primer was used, the surface of the zinc-rich undercoat was wire-brushed before the heat-resistant coating was applied.

Table 3. Preparation of Coated Panels for A/S 502 Launch Exposure (Continued)

Panel No.[1]	Coating Material	Primer[2]	Method of Coating Application	Coating Applied By	General Observations
2-107	1192 Martyte	None		Vendor	
2-250	Dynatherm 700	GE-SS-4155	Trowel	MTB	Application marginal.
2-213	Dynatherm 7275	GE-SS-4155	Brush	MTB	Application satisfactory.
1-202	Dynatherm D-65	D-65A	Brush	MTB	Total of 15 coats applied, then topcoated with No. 904 sealer.
2-203	Dynatherm D-65	D-65A	Brush	MTB	Total of 15 coats applied, then topcoated with No. 904 sealer.
2-104	Dynatherm D-65	D-65A		Vendor	Total of 15 coats applied, then topcoated with No. 904 sealer.
1-139	Dow-Coming 20-103	DC 1200	Trowel	MTB	Application satisfactory.
2-141	Dow-Corning 20-103	DC 1200	Trowel	MTB	Application satisfactory.
1-158	Raycom 435 RPR	None	Brush	MTB	11 coats applied. Satisfactory for brush application.
2-157	Raycom 435 RPR	None	Brush	MTB	11 coats applied. Satisfactory for brush application.
2-126	Raycom 435 RPR	None		Vendor	

1. First digit in this number sequence refers to the designation of the large steel plate (1 or 2) to which the individual panels were attached. Last three digits refer to the particular panel designation.

2. When no primer was used, the surface of the zinc-rich undercoat was wire-brushed before the heat-resistant coating was applied.

Table 3. Preparation of Coated Panels for A/S 502 Launch Exposure (Continued)

Panel No.[1]	Coating Material	Primer[2]	Method of Coating Application	Coating Applied By	General Observations
1-162	Raycom 2138 RPR	None	Trowel	MTB	Adheres to vertical surface but difficult to trowel because of stiffness of mixture.
2-160	Raycom 2138 RPR	None	Trowel	MTB	Adheres to vertical surface but difficult to trowel because of stiffness of mixture.
2-127	Raycom 2138 RPR	None		Vendor	
2-119	Thermo-Lag T-395-1			Vendor	
1-136	Dow-Corning 93-072	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
1-176	Dow-Corning 93-072	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-137	Dow-Corning 93-072	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
2-177	Dow-Corning 93-072	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
1-198	Dow-Corning 92-041	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-196	Dow-Corning 92-041	GE-SS-4155	Trowel	MTB	Application satisfactory.
1-114	Thermo-Lag T-395-4			Vendor	
1-133	GE-RTV-511	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.

1. First digit in this number sequence refers to the designation of the large steel plate (1 or 2) to which the individual panels were attached. Last three digits refer to the particular panel designation.

2. When no primer was used, the surface of the zinc-rich undercoat was wire-brushed before the heat-resistant coating was applied.

Table 3. Preparation of Coated Panels for A/S 502 Launch Exposure (Continued)

Panel No.[1]	Coating Material	Primer[2]	Method of Coating Application	Coating Applied By	General Observations
2-135	GE-RTV-511	GE-SS-4155	Trowel	MTB	Not suitable for vertical surface application.
1-181	PR-1955-BT	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-182	PR-1955-BT	GE-SS-4155	Trowel	MTB	Application satisfactory.
1-187	190-J-7	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-188	190-J-7	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-120	190-J-7			Vendor	Applied to bare steel surface.
2-124	190-J-7			Vendor	
1-191	190-J-4	None	Trowel	MTB	Application satisfactory.
2-190	190-J-4	None	Trowel	MTB	Application satisfactory.
2-123	190-J-4	None		Vendor	
2-125	190-J-4	None		Vendor	Applied to bare steel surface.
1-204	K5NA	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-200	K5NA	GE-SS-4155	Trowel	MTB	Application satisfactory.
2-116	Thermo-Lag T-395-3			Vendor	
2-115	Thermo-Lag T-8006A			Vendor	

1. First digit in this number sequence refers to the designation of the large steel plate (1 or 2) to which the individual panels were attached. Last three digits refer to the particular panel designation.

2. When no primer was used, the surface of the zinc-rich undercoat was wire-brushed before the heat-resistant coating was applied.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
1-168	Korotherm 792-700/792-704	86.5	37.3	56.9	< 204	Spotty char, some edge burn.	Poor
2-164	Korotherm 792-700/792-704	82.6	38.4	53.5	< 204	Spotty char, ridges and valleys.	Fair
2-111	Korotherm 792-700/792-704	112.7	62.1	44.9	< 204	Even ablation, light char.	Good
1-171	Korotherm 792-701/792-702	113.8	50.4	55.7	< 204	Many low spots.	Fair
2-170	Korotherm 792-701/792-702	102.9	44.4	56.9	< 204	Char uneven, some bare areas.	Fair
2-110	Korotherm 792-701/792-702	122.1	60.3	50.6	< 204	Some low spots	Good
1-173	Korotherm 792-703/792-704	86.7	39.0	55.0	< 204	Some high and low spots.	Good
2-172	Korotherm 792-703/792-704	62.7	21.2	66.2	< 204	Some high and low spots.	Good
2-109	Korotherm 792-703/792-704	103.5	64.9	33.7	< 204	Even ablation, several pits.	Good
1-195	Dynatherm E-310F	79.7	47.4	40.5	< 204	Some char, one edge lifted.	Good
2-193	Dynatherm E-310F	62.8	44.5	29.1	< 204	Uniform ablation, some char.	Good

1. Final coating weights recorded here include any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch (Continued)

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
2-102	Dynatherm E-310F	97.6	81.1	16.9	<204	Char layer over 1/2 of area.	Good
1-156	Sperex SP-21	45.6	0	100.0	Not readable	Complete material loss.	Poor
1-153	Sperex SP-21	53.4	1.4	97.4	Not readable	Heavy loss, bare areas.	Poor
1-147	GE-548-300	70.5	25.3	64.1	<204	No char, some holes.	Good
2-145	GE-548-300	71.7	28.5	60.3	<204	No char, some holes.	Good
1-142	GE-548-301	120.2	39.1	67.5	204	Fairly uniform ablation.	Fair
2-144	GE-548-301	107.5	35.5	70.0	260	Heavy ablation, grainy.	Fair
1-148	GE-TBS-542	64.2	56.9	11.4	Not readable	Heavy char, some peeling.	Good
1-150	GE-TBS-542	72.6	64.5	11.2	<204	Heavy char, some edge peel.	Good
1-130	GE-TBS-758	91.9	80.9	12.0	<204	Even ablation, heavy char.	Good
2-132	GE-TBS-758	92.1	86.6	6.0	<204	Even ablation, heavy char.	Good
1-185	1192 Martyte	170.4	28.9	83.0	260	Most material completely ablated.	Poor
2-184	1192 Martyte	152.0	0	100.0	Not readable	Complete material loss.	Poor

1. Final coating weights recorded here include any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch (Continued)

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
2-107	1192 Martyte	112.5	51.8	54.0	Not readable	Uniform ablation.	Good
2-250	Dynatherm 700	--	6.7	--	Not readable	Almost complete loss.	Poor
2-213	Dynatherm 7275	--	0	100.0	Not readable	Complete material loss.	Poor
1-202	Dynatherm D-65	56.0	0	100.0	760	Complete material loss.	Poor
2-203	Dynatherm D-65	59.2	1.5	97.5	760	Peeled appearance, voids.	Poor
2-104	Dynatherm D-65	76.5	41.0	46.4	<204	Uniform ablation.	Good
1-139	Dow-Corning 20-103	85.7	35.3	58.8	<204	Some high and low spots.	Good
2-141	Dow-Corning 20-103	100.6	54.2	46.1	<204	Some high and low spots.	Good
1-158	Raycom 435 RPR	90.7	41.8	53.9	<204	Uneven ablation, heavy char.	Good
2-157	Raycom 435 RPR	94.5	54.5	42.3	<204	Uneven ablation, heavy char.	Good
2-126	Raycom 435 RPR	100.0	77.4	22.6	<204	Uneven ablation, char layer.	Good
1-162	Raycom 2138 RPR	126.3	75.8	40.0	<204	Uneven ablation, high and low spots.	Good
2-160	Raycom 2138 RPR	99.3	66.9	32.6	<204	Uneven ablation, charcoal layer.	Good

1. Final coating weights recorded here include any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch (Continued)

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
2-127	Raycom 2138 RPR	96.0	69.7	27.4	< 204	Even ablation, charcoal layer.	Good
2-119	Thermo-Lag T-395-1	53.4	17.2	67.8	< 204	Even ablation, one corner lifting.	Fair
1-136	Dow-Corning 93-072	81.3	60.7	25.4	Not readable	Finely cracked, little loss.	Good
1-176	Dow-Corning 93-072	47.5	27.5	42.1	< 204	Finely cracked, some corner loss.	Good
2-137	Dow-Corning 93-072	76.3	57.4	24.8	< 204	Finely cracked, little loss.	Good
2-177	Dow-Corning 93-072	53.1	34.5	35.0	< 204	Finely cracked, some deep pits.	Good
1-198	Dow-Corning 92-041	55.0	5.4	90.2	204	Highly variable ablation.	Poor
2-196	Dow-Corning 92-041	45.9	3.4	92.6	204	Complete ablation in some areas.	Poor
1-114	Thermo-Lag T-395-4	--	45.6	--	Not readable	Glassy, complete loss one corner.	Poor
1-133	GE-RTV-511	76.8	45.8	40.4	< 204	Smooth, some light char.	Good

1. Final coating weights recorded here included any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch (Continued)

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
2-135	GE-RTV-511	71.0	48.7	31.4	<204	Smooth, some light char.	Good
1-181	PR-1955-BT	66.4	17.5	73.6	<204	Uniform ablation, no char.	Fair
2-182	PR-1955-BT	68.5	26.4	61.5	<204	Uniform ablation, no char.	Fair
1-187	190-J-7	54.6	1.8	96.7	<204	Almost complete loss	Poor
2-188	190-J-7	67.3	18.7	72.2	<204	Uneven ablation, spotty char.	Fair
2-120	190-J-7	45.3	1.4	96.9	Not readable	Almost complete ablation.	Fair
2-124	190-J-7	42.7	3.0	93.0	<204	Almost complete ablation.	Fair
1-191	190-J-7	78.5	35.4	54.9	<204	Char layer, some low spots.	Fair
2-190	190-J-4	82.0	45.3	44.8	<204	Black char, no bare spots.	Good
2-123	190-J-4	54.9	4.0	92.7	<204	Ablated to thin char.	Poor
2-125	190-J-4	53.6	5.2	90.3	<538	Complete material loss.	Poor
1-204	K5NA	46.5	2.5	95.6	Not readable	Uneven ablation, one corner lost.	Poor

1. Final coating weights recorded here include any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 4. Results of Booster Engine Exhaust Exposure, A/S 502 Launch (Continued)

Panel No.	Coating Material	Initial Coating Weight (grams)	Final Coating Weight[1] (grams)	Weight Loss[2] (%)	Back-Face Temperature[3] (°C)	General Observations	Rating
2-200	K5NA	48.1	4.5	90.6	<204	Considerable ablation, uneven.	Poor
2-116	Thermo-Lag T-395-3	39.5	26.0	34.2	<204	Cracked surface, even ablation.	Good
2-115	Thermo-Lag T-8006A	67.4	51.3	23.9	Not readable	Laminated appearance, charcoal.	Fair

1. Final coating weights recorded here include any char that may have formed.

2. Prior to char removal.

3. As indicated by color change of Tempilaq temperature-sensitive paints.

Table 5. Refurbishment of Coating Materials Following A/S 502 Launch Exposure

Panel No.	Coating Material	Char Removal[1] Thickness Loss (%)	Char Removal[1] Weight Loss (%)	Preparation and Observations
2-109	Korotherm 792-703/792-704	0	1.0	Cleaned readily with wire brush.
1-173	Korotherm 792-703/792-704	0	0.3	New coating appears to adhere well to prior coating.
2-110	Korotherm 792-701/792-702	32	2.0	Surface wire-brushed and recoated. New coating appears to adhere well to prior coating.
2-111	Korotherm 792-700/792-704	4	0.7	Surface wire-brushed and recoated. New coating appears to adhere well to prior coating.
2-193	Dynatherm E-310F	8	3.5	Cleaned with wire brush, wiped with acetone. New coating stiff to apply, adheres well.
2-141	Dow-Corning 20-103	0	0.4	New material can be separated (with difficulty) from prior coating.
2-137	Dow-Corning 93-072	20	4.0	New coating did not cure readily. Separated from prior coating easily.
1-176	Dow-Corning 93-072	20	6.3	New coating did not cure readily. Separated from prior coating easily.
2-160	Raycom 2138 RPR	24	26.8	New coating applies uniformly; appears to adhere well to prior coating.
2-126	Raycom 435 RPR	Highly variable	17.0	Material brushed on in thin layers; appears to adhere well.
2-157	Raycom 435 RPR	Highly variable	7.0	Material brushed on in thin layers; appears to adhere well.
1-147	GE-548-300	0	0	Old surface cleaned with wire brush, wiped with acetone, and roughened with abrasive paper. New material trowelled on; adheres well.

1. Material loss in thickness and weight by char removal in preparation for recoating. Percentages shown refer to original coating weights and coating thicknesses.

Table 5. Refurbishment of Coating Materials Following A/S 502 Launch Exposure (Continued)

Panel No.	Coating Material	Char Removal[1] Thickness Loss (%)	Char Removal[1] Weight Loss (%)	Preparation and Observations
1-150	GE TBS-542	55	21.0	Wire-brush-cleaned, wiped with acetone, roughened with abrasive paper. New material adheres well.
1-130	GE TBS-758	52	23.0	Heavy char, wire-brush-removed easily. Surface acetone-wiped; new coating thin, does not cure readily.
1-133	GE RTV-511	0	0	Wire-brush-cleaned, wiped with acetone. New material poured on prior coating; separates easily at edges.
2-107	Martyte 1192	0	0.3	Little char. Surface acetone wiped. New coating applies readily, appears to adhere well.
2-190	190-J-4	8	5.4	Char removed readily by wire brush. Surface acetone-wiped, new coating trowelled on easily, adheres well.
2-116	Thermo-Lag T-395-3	0	2.5	No material available for recoating.
2-104	Dynatherm D-65	(Not obtained)		Wire-brushed, acetone-wiped. New coating applied in several coats to original total thickness.

1. Material loss in thickness and weight by char removal in preparation for recoating. Percentages shown refer to original coating weights and coating thicknesses.

Table 6. Results of Booster Engine Exhaust Exposure, A/S 503 Launch

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
137	DC 93-072	Refurbished[1]	45.3	37.2	48.5	--[2]	<121	Small char area, one corner only.
109	Korotherm 792-703/ 792-704	Refurbished[1]	78.9	56.0	--	--	<121	No char. Complete loss "old" coating.
160	Raycom RPR 2138	Refurbished[1]	47.8	--	55.5	41.7	<121	Black char. Uneven.
195	Dynatherm E-310F	Refurbished[1]	47.2	--	51.4	31.8[3]	<121	Thin char.
150	GE TBS-542	Refurbished[1]	100.0	100.0	--	--	>260	No material remaining on panel.
104	Dynatherm D-65	Refurbished[1]	88.2	83.5	--	--	<121	No char.
147	GE 548-300	Refurbished[1]	83.1	75.5	--	--	218-232	No char. One spot reached 246°C.
107	Martyte 1192	Refurbished[1]	84.0	80.8	--	--	<121	No char.
141	DC 20-103	Refurbished[1]	76.0	68.8	--	--	<121	No char.

1. Half of "refurbishment" panel had original coating exposed during AS-502 launch. Other half of panel was recoated with same material to produce thickness of 0.318 cm.

2. Char was on one corner of sample only.

3. Char layer was too uneven to obtain meaningful thickness measurement prior to char removal.

Table 6. Results of Booster Engine Exhaust Exposure, A/S 503 Launch (Continued)

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
133	GE RTV 511	Refurbished[1]	62.7	55.4	66.1	--	<121	No char on "new" coating.
190	Fuller 190-J-4	Refurbished[1]	76.1	--	79.0	62.2	163-177	
130	GE TBS-758	Refurbished[1]	11.7	37.4 (increase)	39.0	29.0	<121	Thick char, even ablation.
149	Dynatherm E-320	Zinc-rich paint over steel	43.1	--	45.8	43.1	<121	Very light char. Even ablation.
134	Dynatherm E-320	Bare steel	51.7	37.8	55.0	47.1	<121	Very light char. Even ablation.
A	GE TBS-758	Bare steel	5.7	57.7 (increase)	25.4	20.1	<121	Thick char, even ablation.
B	DC 93-072	Bare steel	41.2	--	47.6	40.2	<121	Little char, even ablation.
C	GE 548-300	Bare steel	81.4	76.8	--	--	149-163	One spot reached 246°C.
D	DC 20-103	Bare steel	81.5	76.5	--	--	<121	No char, even ablation.

1. Half of "refurbishment" panel had original coating exposed during AS-502 launch. Other half of panel was recoated with same material to produce thickness of 0.318 cm.

Table 6. Results of Booster Engine Exhaust Exposure, A/S 503 Launch (Continued)

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
E	792-703/792-704	Bare steel	53.9	46.2	--	--	< 121	Light char around edges.
F	Dynatherm E-310F	Bare steel	36.9	30.4	--	--	< 121	Little char.
G	Dynatherm D-65	Bare steel	(This panel had only 0.159-cm-thick coating initially; virtually all of the material had ablated)				246	
H	Martyte 1192	Bare steel	86.5	81.8	--	--	< 121	No char.
I	DC 93-072	D-65 base layer	24.9	11.5	28.5	20.4	< 121	Even ablation.
L	DC 20-103	D-65 base layer	63.7	42.6	--	--	< 121	No char.
M	GE 548-300	D-65 base layer	63.7	42.6	--	--	< 121	No char.
P	GE TBS-758	D-65 base layer	6.2	56.9 (increase)	24.1	12.6	< 121	Thick char, even ablation.
Q	792-703/792-704	D-65 base layer	54.2	42.9	--	--	< 121	Very light char.
T	Martyte 1192	D-65 base layer	(All of the 1192 coating was missing)				177-204	One spot reached 246°C.
V	Dynatherm E-310F	D-65 base layer	31.3	20.4	34.4	24.2	< 121	Thin char, even ablation.
W	Raycom RPR 2138	D-65 base layer	37.3	40.5	32.4	41.3	< 121	Fairly even ablation.

Table 7. Results of Booster Engine Exhaust Exposure, A/S 505 Launch

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
R-1	E-310F	Zinc-coated steel	19.3	20.6	--	--	<65.6	Insignificant char.
H-1	20-103	Zinc-coated steel	43.5	31.7	--	--	<65.6	No char.
S-1	E-320	Zinc-coated steel	26.9	22.8	--	--	<65.6	Insignificant char.
N-1	792-703/792-704	Zinc-coated steel	51.4	47.2	--	--	<65.6	Insignificant char.
A-1	Upcote 16030[1]	Zinc-coated[2] steel	16.4	3.1	--	--	<65.6	Insignificant char.
F-1	Dow-Corning 93-058	Zinc-coated steel	100.0	100.0	--	--	>260	Complete coating loss.
C-1	Goodrich EP-87	Zinc-coated steel	1.0	54.4 (increase)	10.0	1.4	<65.6	Heavy black char, easily brushed away.
F	Upcote 14038	Bare steel	22.1	22.2	--	--	<65.6	Insignificant char.
J	Upcote 07-006	Bare steel	34.5	22.1	--	--	<65.6	Insignificant char.

1. Coating separated from steel panel during examination.

2. The Universal Propulsion coatings applied to zinc-painted test panels were prepared by the Materials Testing Branch. Those applied to bare steel panels were prepared by the vendor.

Table 7. Results of Booster Engine Exhaust Exposure, A/S 505 Launch (Continued)

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
J-1	93-072	Zinc-coated steel	18.5	5.7	23.9	17.6	<65.6	Deep, light char. Some loss during handling.
G	Upcote 10035	Bare steel	38.2	32.1	--	--	<65.6	Insignificant char.
A	Upcote 14050	Bare steel	51.7	37.5	--	--	<65.6	No char.
U-1	E-320	Zinc-coated steel	28.4	30.4	--	--	<65.6	Insignificant char.
M-1	792-703/792-704	Zinc-coated steel	61.6	63.6	--	--	<65.6	Insignificant char.
I-1	20-103	Zinc-coated steel	43.9	38.1	--	--	<65.6	No char.
Q-1	E-310F	Zinc-coated steel	42.2	42.0	--	--	<65.6	Insignificant char.
K-1	93-072	Zinc-coated steel	21.2	6.2	27.3	26.2	<65.6	Deep, light char.
D-1	Goodrich N322	Zinc-coated steel	21.1	24.8	--	--	<65.6	Insignificant char.
154	D-65	Zinc-coated steel	99.0	99.0	--	--	246	Original coating only 0.180 cm thick.
E	Upcote 14038	Bare steel	32.6	9.2	--	--	<65.6	Insignificant char.
C	Upcote 14041	Bare steel	33.3	30.3	--	--	<65.6	Insignificant char.

Table 7. Results of Booster Engine Exhaust Exposure, A/S 505 Launch (Continued)

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
B-1	Upcote 16031	Zinc-coated[2] steel	19.5	19.4	--	--	<65.6	Insignificant char.
D	Upcote 14041	Bare steel	22.2	21.6	--	--	<65.6	Insignificant char.
I	Upcote 07006	Bare steel	19.3	20.9	--	--	<65.6	Insignificant char.
B	Upcote 14050	Bare steel	42.2	20.7	--	--	<65.6	Insignificant char.
E-1	Goodrich N-355	Zinc-coated steel	54.6	47.6	--	--	<65.6	No char.
L-1	93-072	Zinc-coated steel	10.4	6.2	25.2	18.4	<65.6	Deep, light char.
O-1	792-703/792-704	Zinc-coated steel	49.5	48.6	--	--	<65.6	No char.
T-1	E-320	Zinc-coated steel	34.2	24.4	--	--	<65.6	Insignificant char.
P-1	E-310F	Zinc-coated steel	29.6	22.1	--	--	<65.6	Insignificant char.
G-1	20-103	Zinc-coated steel	50.5	50.4	--	--	<65.6	Insignificant char.
H	Upcote 10035	Bare steel	24.6	5.7	--	--	<65.6	Insignificant char.
206	D-65	Zinc-coated steel	82.7	77.2	--	--	<65.6	Insignificant char.

2. The Universal Propulsion coatings applied to zinc-painted test panels were prepared by the Materials Testing Branch. Those applied to bare steel panels were prepared by the vendor.

Table 7. Results of Booster Engine Exhaust Exposure, A/S 505 Launch (Continued)

Panel No.	Material	Applied To	Weight Loss Before Char Removal (%)	Thickness Loss Before Char Removal (%)	Weight Loss After Char Removal (%)	Thickness Loss After Char Removal (%)	Maximum Back-Face Temperature, (°C)	Remarks
	Inorganic zinc paint	Bare steel, 0.318 cm	--	--	--	--	>260	Zinc paint slightly affected by heat.
	Inorganic zinc paint	Bare steel, 0.318 cm	--	--	--	--	>260	Zinc paint slightly affected.
	Inorganic zinc paint	Bare steel, 0.635 cm	--	--	--	--	204	Zinc paint unaffected.
	Inorganic zinc paint	Bare steel, 1.27 cm	--	--	--	--	107	Zinc paint unaffected.
	Inorganic zinc paint	Bare steel, 1.905 cm	--	--	--	--	107	Zinc paint unaffected.
	Inorganic zinc paint	Bare steel, 2.54 cm	--	--	--	--	107	Zinc paint unaffected.

Table 8. Adhesion Characteristics[1] of Fifteen Ablative Materials Evaluated in the A/S 502 Launch-Exposure Test

Material	Peel Strength (gm/cm)
GE RTV-511	≤178.6
GE TBS 758	3,036.2
DC 20-103	1,428.8
DC 93-072	4,822.2
GE TBS-542	≤178.6
GE 548-300	>Tensile strength of material[3]
Dynatherm E-310F	2,679
Fuller 190-J-4	>Tensile strength of material[2]
Korotherm 792-700/790-704	>Tensile strength of material[3]
Korotherm 792-703/792-704	>Tensile strength of material[3]
Korotherm 792-701/792-702	>Tensile strength of material[3]
Raycom RPR 2138	(Stripped paint from steel)
Martyte-Presstite 1192	(Stripped paint from steel)
Raycom RPR 435	<178.6
Dynatherm D-65	4,822.2

1. Ablative material 0.318 cm applied to zinc-painted steel.

2. Material spalls away in small pieces; basic adhesion characteristics poor - material separates at paint interface.

3. Materials rupture but remove paint from steel base, indicating good basic adhesion characteristics.

Table 9. Adhesion Characteristics of Several Ablative Materials Applied to Bare Steel

Material	Peel Strength (gm/cm)
GE TBS-758	893.0
DC 20-103	1,071.6
DC 93-072	4,107.8
GE 548-300	>Tensile strength of material
Dynatherm E-310F	893.0
Korotherm 792-700/790-704	>Tensile strength of material
Martyte Presstite 1192	(Material peeled away from steel base and fractured before load value could be obtained.)

Table 10. Adhesion Characteristics of Four Ablative Materials Applied over a D-65 Surface

Material	Peel Strength (gm/cm)
DC 20-103	714.4
Dynatherm E-310F	2,679.0
Raycom RPR 2138	3,572.0
Korotherm 792-703/792-704	(exceeded tensile strength of material)

Table 11. Flammability Characteristics of Fifteen Ablative Materials Evaluated in the A/S 502 Launch-Exposure Tests

Material	Burn Time[1] (Sec)	Burn Time[2] (Sec)	Material Burned Beyond Edge of Heat Sink
Dynatherm D-65	4	4	No
DC 93-072	4	5	No
Fuller 190-J-4	8	8	No
GE RTV-511	15	30	No
GE TBS-542	25	11	No
Korotherm 792-703/792-704	25	41	No
GE TBS-758	30	30	No
GE 548-300	37	40	No
Dynatherm E-310F	60	78	No
DC 20-103	105	80	No
Korotherm 792-700/790-704	160[3]	105	Yes
Raycom RPR 435	195	267	Yes
Martyte Presstite 1192	240	136	No
Korotherm 792-701/792-702	300	252	Yes
Raycom RPR 2138	345	210	No
Dynatherm E-320	110	102	No
Upcote 10-035[4]	--[4]	--[4]	No

1. Sample supported horizontally as cantilever.

2. Sample supported horizontally on aluminum plate with 2.54-cm overhang.

3. Flame engulfed sample.

4. Specimen could not be ignited.

Table 12. Flammability Characteristics of Four Ablative Materials of Two Different Thicknesses

Materials	Burn Time (sec) 0.318 cm Thickness	Burn Time (sec) 0.635 cm Thickness
Raycom RPR 2138	160	102
Korotherm 792-703/792-704	36	26
Dynatherm E-310F	152	70
Dow-Corning 20-103	64	57

Table 13. Flammability Characteristics of Five Ablative Materials Tested in Accordance with ASTM-D635

Material	Burn Time (sec)	Burning Characteristics	Flame Propagation Before Extinction
Dow-Corning 20-103	20[1]	Very small flame	0.635 to 1.27 cm
Dynatherm E-310F	100	Vigorous burning	1.27 cm
Dynatherm D-65	1-2	Very small flame	<0.318 cm
Raycom RPR 2138	Vigorous burning, all of specimen consumed.		
Korotherm 792-703/792-704	8	Flame medium	<1.27 cm

1. Sample glowed for 22 seconds after flame extinguished.

Table 14. Results of LOX-Impact Tests on Ablative Materials

MAB Test No.	Material	Condition	Average Thickness (cm)	No. of Trials (Drops)	Reactions: Faint	Reactions: Slight	Reactions: Appreciable	Reactions: Considerable	Reactions: Audible Reports	Reactions: Total Reactions
1	DC-20-103	MAB Preparation. Lab-Clean[1].	0.300	20	5	5	0	1	0	11
2	D-65	MAB Preparation. Exposed to atmosphere for 16 days[1].	0.328	20	0	0	0	0	0	0
3	DC-20-103	MAB Preparation. Exposed to atmosphere for 16 days[1].	0.353	20	3	6	0	3	0	12
4	DC-93-072	MAB Preparation. Lab-Clean[1].	0.295	20	7	5	1	1	0	14
5	E-310F	MAB Preparation. Lab-Clean[1].	0.292	20	0	0	0	0	0	0
7	D-65 Tape + 904	MAB Preparation. Lab-Clean[1].	0.079	10	0	0	0	0	0	0
8	D-65 Tape + 904	MAB Preparation. Hydraulic oil brushed on surface.	0.079	5	0	0	2	0	2 (violent)	2
10	DC-20-103	MAB Preparation. Hydraulic oil brushed on surface.	0.300	4	0	1	0	0	0	1

1. Striker pins precooled in LN_2. Samples and cups conditioned for 1,800 seconds in LOX "freeze box."

NOTE: Because of the several departures from testing procedures specified in MSFC-SPEC-106B (Reference 4), the data presented here should not be considered as certifying these materials as either sensitive or not sensitive to LOX impact.

Table 14. Results of LOX-Impact Tests on Ablative Materials (Continued)

MAB Test No.	Material	Condition	Average Thickness (cm)	No. of Trials (Drops)	Reactions: Faint	Slight	Appreciable	Considerable	Audible Reports	Total Reactions
11	DC-20-103	MAB Preparation. Lab-Clean[1].	0.295	4	1	2	0	0	0	3
12	792-703/792-704	MAB Preparation. Washed in F-33[1].	0.307	20	0	1	0	0	0	1
13	E-320	MAB Preparation. Lab-Clean[1].	0.307	20	0	0	0	0	0	0
14	RPR 2138	MAB Preparation. Lab-Clean[1].	0.318	20	0	2	1	1	1	4
16	TBS 758	MAB Preparation. Lab-Clean[1].	0.300	20	3	2	1	3	2	9
17	D-65	Mobile Launcher #2, tower leg[2].	0.206	20	4	5	6	0	12	15
18	D-65	Mobile Launcher #2, tower leg[2].	0.196	20	2	3	11	0	4	16
19	D-65	Mobile Launcher #2, tower leg[2].	0.340	20	1	0	1	0	1	2
20	DC-20-103	Mobile Launcher #2, camera stand[2].	0.465	8	0	0	0	0	0	0
21	D-65	Mobile Launcher #2, tower leg[2].	0.483	10	0	0	0	0	0	0

1. Striker pins precooled in LN_2. Samples and cups conditioned for 1,800 seconds in LOX "freeze box."

2. Striker pins precooled in LN_2. Samples and cups not conditioned; LOX added 10 seconds prior to drop.

NOTE: Because of the several departures from testing procedures specified in MSFC-SPEC-106B (Reference 4), the data presented here should not be considered as certifying these materials as either sensitive or not sensitive to LOX impact.

Table 14. Results of LOX-Impact Tests on Ablative Materials (Continued)

MAB Test No.	Material	Condition	Average Thickness (cm)	No. of Trials (Drops)	Reactions: Faint	Slight	Appreciable	Considerable	Audible Reports	Total Reactions
22	DC-20-103	Mobile Launcher #2, camera stand, zero level[2].	0.490	20	1	3	0	0	0	4
23	DC-20-103	Mobile Launcher #2, camera stand, zero level[2].	0.513	20	1	0	0	0	0	1
24	D-65	Mobile Launcher #2, camera box[2].	0.173	5	0	0	0	0	0	1
25	DC-20-103	Mobile Launcher #2, camera stand, zero level[2].	0.478	30	2	0	1	0	0	3
26	DC-20-103	MAB Preparation. Lab-Clean[2].	0.340	20	0	0	0	0	0	0
27	E-310F	MAB Preparation. Lab-Clean[2].	0.439	20	0	0	0	0	0	0
28	TBS-758	MAB Preparation. Lab-Clean[2].	0.368	20	0	0	0	0	0	0
29	792-703/792-704	MAB Preparation. Lab-Clean[2].	0.343	20	0	0	0	0	0	0
30	D-65	Mobile Launcher #2, tower leg[3].	0.114 to 0.191	5	0	0	3	0	3	3

2. Striker pins precooled in LN_2. Samples and cups not conditioned; LOX added 10 seconds prior to drop.

3. Special test: Sample base flat plate not recessed for cup; cups and striker pins not used; sample placed on stainless steel plate, LOX poured on sample for 3 seconds, stainless steel disc placed on top of sample; impacted with plummet.

NOTE: Because of the several departures from testing procedures specified in MSFC-SPEC-106B (Reference 4), the data presented here should not be considered as certifying these materials as either sensitive or not sensitive to LOX impact.

Table 14. Results of LOX-Impact Tests on Ablative Materials (Continued)

MAB Test No.	Material	Condition	Average Thickness (cm)	No. of Trials (Drops)	Reactions					
					Faint	Slight	Appreciable	Considerable	Audible Reports	Total Reactions
30	D-65	Mobile Launcher #2, tower leg[3].	0.312 to 0.493	15	0	0	0	0	0	0
31	20-103	MAB Preparation. Lab-Clean[3].	0.109 to 0.272	20	0	0	0	0	0	0
32	E-320	MAB Preparation. Lab-Clean[2].	0.351	20	0	0	0	0	0	0
33	DC-93-072	MAB Preparation. Lab-Clean[2].	0.330	20	1	0	0	2	0	3
34	RPR 2138	MAB Preparation. Lab-Clean[2].	0.366	20	0	0	0	0	0	0
35	DC-93-058	MAB Preparation. Lab-Clean.	0.348	20	7	10	1	0	0	18
36	Goodrich EP 87	Sheet samples, Lab-Clean[2].	0.353	20	0	0	0	0	0	0
37	Goodrich N-322	Sheet samples, Lab-Clean.	0.353	20	0	0	0	0	0	0
38	Goodrich N-355	Sheet samples, Lab-Clean.	0.320	20	0	0	0	0	0	0

2. Striker pins precooled in LN_2. Samples and cups not conditioned; LOX added 10 seconds prior to drop.

3. Special test: Sample base flat plate not recessed for cup; cups and striker pins not used; sample placed on stainless steel plate, LOX poured on sample for 3 seconds, stainless steel disc placed on top of sample; impacted with plummet.

NOTE: Because of the several departures from testing procedures specified in MSFC-SPEC-106B (Reference 4), the data presented here should not be considered as certifying these materials as either sensitive or not sensitive to LOX impact.

Table 14. Results of LOX-Impact Tests on Ablative Materials (Continued)

MAB Test No.	Material	Condition	Average Thickness (cm)	No. of Trials (Drops)	Reactions: Faint	Slight	Appreciable	Considerable	Audible Reports	Total Reactions
43	DC-20-103	MAB Preparation. Hydraulic fluid on surface[4].	0.312	20	0	0	0	0	0	0
44	E-310-F	MAB Preparation. Hydraulic fluid on surface[4].	0.384	20	0	0	0	0	0	0
64	Dynatherm E-320	MAB Preparation. Hydraulic fluid on surface[4].	0.345	20	0	0	0	0	0	0
65	Korotherm 792-703/792-704	MAB Preparation. Hydraulic fluid on surface[4].	0.348	20	0	0	0	0	0	0

4. MIL-H-5606B hydraulic fluid brushed on surface of specimens, allowed to stand 1 day, and then surface-wiped prior to impact test. Striker pins precooled in LN_2; cups and samples not conditioned; LOX added 10 seconds prior to drop.

NOTE: Because of the several departures from testing procedures specified in MSFC-SPEC-106B (Reference 4), the data presented here should not be considered as certifying these materials as either sensitive or not sensitive to LOX impact.

Table 15. Summary of Torch Test Results

Materials	Insulation Index (sec/cm) ΔT80°C	Insulation Index (sec/cm) ΔT180°C	Insulation Index (sec/cm) ΔT380°C	Erosion Rate (cm/sec)	Comparative Launch Exposure Test Results (Average) Weight Loss (%)
GE 548-300	47	104	247	0.0024	69
GE TBS-542	74	142	--[1]	0.0037	66[3]
GE TBS-758	98	167	233	0.0032	31
GE RTV-511	66	121	207	0.0045	51
Dynatherm E-310F	82	190	--[1]	0.0017	34
Dow-Corning 93-072	61	103	148	0.0066	34
Dow-Corning 20-103	60	135	270	0.0016	56[4]
Martyte 1192-1	41	67	98	0.0089	86
Fuller 190-J-4	97	142	--[1]	0.0068	76
Raycom 435 RPR	40	73	123	---[2]	48
Raycom 2138 RPR	59	106	159	0.0061	54

1. Missing data indicates sample burned through prior to reaching indicated ΔT, or that test time (180 sec) elapsed before ΔT was reached.

2. This sample delaminated during burn.

3. Weight loss was 11% to 32% during AS-502, and 100% during AS-503

4. Weight loss range from 32% to 82%.

Table 15. Summary of Torch Test Results (Continued)

Materials	Insulation Index (sec/cm) ΔT80°C	ΔT180°C	ΔT380°C	Erosion Rate (cm/sec)	Comparative Launch Exposure Test Results (Average) Weight Loss (%)
Dynatherm D-65	95	--[1]	--[1]	0.0068	72[5]
Korotherm 792-700/790-704	28	65	--[1]	0.0172	52
Goodrich EP-87	110	241	248	0.0037	10
Korotherm 792-703/792-704	81	117	--[1]	0.0085	56
Dynatherm E-320	110	166	--[1]	0.0055	41

1. Missing data indicates sample burned through prior to reaching indicated ΔT, or that test time (180 sec) elapsed before ΔT was reached.

5. Weight loss ranged from 46% to 100%.

Table 16. Summary of Results of Various Tests on Ablative Materials

Materials	Application[1]	Rocket Engine Exhaust[5]	Flammability (per ASTM D-635 or D-1692-62T)	Hypergolic Propellant Exposure (Simulated Spillage)	LOX Exposure (Simulated Spillage)	Flexibility	Adhesion
Korotherm 792-700/790-704	Unsatisfactory	Poor-Good	Unsatisfactory	Not tested	Not tested	Not tested	Satisfactory
Korotherm 792-701/792-702	Unsatisfactory	Poor-Good	Unsatisfactory	Not tested	Not tested	Not tested	Satisfactory
Korotherm 792-703/792-704	Satisfactory	Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Dynatherm E-310F	Satisfactory	Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Sperex SP-21	(Brush)	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
GE-548-300[5]	Satisfactory	Poor-Good	Not tested	Not tested	Not tested	Satisfactory	Satisfactory
GE 548-301	Unsatisfactory	Fair	Not tested	Not tested	Not tested	Not tested	Not tested
GE TBS-542	Unsatisfactory	Poor-Good	Not tested	Not tested	Not tested	Satisfactory	Unsatisfactory
GE TBS-758	Unsatisfactory	Good	Not tested	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Martyte 1192	Satisfactory	Poor	Not tested	Not tested	Not tested	Unsatisfactory	Unsatisfactory
Dynatherm 700	--[2]	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
Dynatherm 7275	(Brush)	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
Dynatherm D-65	Satisfactory[3]	Poor-Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory

1. For trowelable materials, must be applicable to a vertical surface. Materials also required to cure within 10 days under ambient conditions.

2. Application data for this material not available.

3. This material may be applied by brush, spray, or as sheet or tape.

5. Material must receive one "Good" rating to be eligible for further testing beyond AS-502. Some materials were found to rate "Poor" on subsequent testing.

Table 16. Summary of Results of Various Tests on Ablative Materials (Continued)

Materials	Application[1]	Rocket Engine Exhaust[5]	Flammability (per ASTM D-635 or D-1692-62T)	Hypergolic Propellant Exposure (Simulated Spillage)	LOX Exposure (Simulated Spillage)	Flexibility	Adhesion
Dow-Corning 20-103	Satisfactory	Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Raycom 435 RPR	(Brush)	Good	Unsatisfactory	Not tested	Not tested	Not tested	Unsatisfactory
Raycom 2138 RPR	Unsatisfactory	Good	Unsatisfactory	Satisfactory	Satisfactory	Unsatisfactory	Satisfactory
Thermo-Lag T-395-1	(Brush)	Fair	Not tested	Not tested	Not tested	Not tested	Not tested
Dow-Corning 93-072	Unsatisfactory	Good	Not tested	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Dow-Corning 92-041	Satisfactory	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
Thermo-Lag T-395-4	(Not tested, Vendor-applied)	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
GE RTV-511	Unsatisfactory	Good	Not tested	Not tested	Not tested	Satisfactory	Unsatisfactory
PR 1955 BT	Satisfactory	Fair	Not tested	Not tested	Not tested	Not tested	Not tested
Fuller 190-J-7	Satisfactory	Poor-Fair	Not tested	Not tested	Not tested	Not tested	Not tested
Fuller 190-J-4	Satisfactory	Poor-Good	Not tested	Not tested	Not tested	Not tested	Unsatisfactory
Armstrong K5NA	Satisfactory	Poor	Not tested	Not tested	Not tested	Not tested	Not tested
Thermo-Lag T-395-3	(Not tested, Vendor-applied)	Good[6]	Not tested	Not tested	Not tested	Not tested	Not tested

1. For trowelable materials, must be applicable to a vertical surface. Materials also required to cure within 10 days under ambient conditions.

5. Material must receive one "Good" rating to be eligible for further testing beyond AS-502. Some materials were found to rate "Poor" on subsequent testing.

6. Material was rated "Good" in initial tests, but vendor did not supply additional material for further testing.

Table 16. Summary of Results of Various Tests on Ablative Materials (Continued)

Materials	Application[1]	Rocket Engine Exhaust[5]	Flammability (per ASTM D-635 or D-1692-62T)	Hypergolic Propellant Exposure (Simulated Spillage)	LOX Exposure (Simulated Spillage)	Flexibility	Adhesion
Thermo-Lag T-8006A	(Not tested, Vendor-applied)	Fair	Not tested	Not tested	Not tested	Not tested	Not tested
Dynatherm E-320	Satisfactory	Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Dow-Corning 93-058	Satisfactory	Poor	Not tested	Not tested	Satisfactory	Satisfactory	Unsatisfactory
Goodrich EP-87	--[4]	Good	Satisfactory	Not tested	Satisfactory	Satisfactory	Satisfactory
Goodrich N-322	--[4]	Good	Unsatisfactory	Not tested	Satisfactory	Satisfactory	Satisfactory
Goodrich N-355	--[4]	Good	Unsatisfactory	Not tested	Satisfactory	Satisfactory	Satisfactory
Upcote 16030	Satisfactory	Good	Not tested	Not tested	Not tested	Not tested	Not tested
Upcote 14038	(Not tested, Vendor-applied)	Good	Not tested	Not tested	Not tested	Not tested	Not tested
Upcote 07006	(Not tested, Vendor-applied)	Good	Not tested	Not tested	Not tested	Not tested	Not tested
Upcote 10035	Satisfactory	Good	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory

1. For trowelable materials, must be applicable to a vertical surface. Materials also required to cure within 10 days under ambient conditions.

4. These materials furnished as cured sheet in proper thickness, to be cemented to substrate. Consequently, they do not meet the basic application requirement as presently stated.

5. Material must receive one "Good" rating to be eligible for further testing beyond AS-502. Some materials were found to rate "Poor" on subsequent testing.

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Table 16. Summary of Results of Various Tests on Ablative Materials (Continued)

Materials	Application[1]	Rocket Engine Exhaust[5]	Flammability (per ASTM D-635 or D-1692-62T)	Hypergolic Propellant Exposure (Simulated Spillage)	LOX Exposure (Simulated Spillage)	Flexibility	Adhesion
Upcote 14050	(Not tested, Vendor-applied)	Good	Not tested	Not tested	Not tested	Not tested	Not tested
Upcote 14041	(Not tested, Vendor-applied)	Good	Not tested	Not tested	Not tested	Not tested	Not tested
Upcote 16031	Satisfactory	Good	Not tested	Not tested	Not tested	Not tested	Not tested

1. For trowelable materials, must be applicable to a vertical surface. Materials also required to cure within 10 days under ambient conditions.

5. Material must receive one "Good" rating to be eligible for further testing beyond AS-502. Some materials were found to rate "Poor" on subsequent testing.

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